Collision Avoidance for autonomous ships (MASS): making assumptions about other ships intended routes

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Research on Maritime Autonomous Surface Ships (MASS) have considerably gained momentum. Norway's first "autonomous" short-sea container vessel, Yara Birkeland, has started to sail in 2022, albeit in the beginning with crew onboard. Within a new 8 year-long research project, SFI AutoShip, automatic collision avoidance is studied. This paper argues that a crucial point for the safety of autonomous navigation is the assumptions made about other ship's intended routes. In this paper a discussion and a concept for a methodical approach and available methods are presented. At the same time, it is important to make these assumptions readily visible for operators in a shore control centre. The paper concludes with pointing to the e-navigation features "route exchange" and "moving havens" as possible contributors to knowledge of other ships intentions.

Keywords: Maritime Autonomous Surface Ships (MASS), collision avoidance, COLREGS, e-navigation, route exchange, intended route.

1. Introduction

Research on Maritime Autonomous Surface Ships (MASS) have considerably gained momentum since the IMO opened for integration of "new and advancing technologies" in its regulatory framework in 2017.

Within a new 8 year-long research project, SFI AutoShip, the safety of MASS operations is researched. Within the design domain Human-Machine Interfaces for operators in remote operations centre are studied and in the computer science domain studies are made on automatic collision avoidance. In several projects good progress has been made solving simple situations according to the collision regulations (COLREGS) (e.g. Brekke, 2019). A major hurdle remains in translating qualitative terms like "early and substantial" or "the ordinary practice of seamen" into enumerations useful for computer algorithms. It will be important to make the automatic maneuvers of an autonomous ship understandable for humans on conventional ships, and it will be equally important for the automatic algorithms to understand the maneuvers of human navigators on conventional ships. In Norway a first all-electric autonomous short-sea container vessel, Yara Birkeland, has been delivered. It has been delayed but has now started to sail in 2022. In the beginning with a crew onboard but automation will be tested and introduced as time goes by. One crucial aspect for the automation system will be to decide on the intentions of other manned or autonomous vessels. In order to do that the system will have to make assumptions about their intentions and these assumptions has to be transparent in order to avoid misunderstandings.

The aim of this paper is to discuss different methods of making these assumptions. They then have to be made salient for human operators.

I will illustrate the importance of such assumptions by an example from conventional shipping.

1.1. The case of *Karin Høj* and *Scott Carrier*

On December 13, 2021, the 90 meters long British general cargo vessel *Scot Carrier* collided with the 55 meters long Danish barge *Karin Høj* south of Svartgrund buoy in the Bornholm Strait. The collision happened in in fog and darkness at 0330 in the morning.

The area is busy, and a Traffic Separation Scheme (TSS) is in place (IMO, 1998). See Figure 1. Ships traveling southwest from the

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Baltic Sea towards the North Sea through the Øresund, between Sweden and Denmark, The Big Belt or the Kiel Canal passes through here. The TSS merges the traffic along the Swedish south coast towards Øresund, and the traffic for the Big Belt and the Kiel Canal. The area south of Svartgrund where the two lanes split are marked as a precautionary area because of risks of traffic conflicts.

Scot Carrier was on a south-westerly course bound for Montrose in Scotland by way of Øresund. This meant that she had to turn starboard (right) after the Svartgrund buoy in the precautionary area.

Fig. 1. The Bornholm Strait between the Danish island Bornholm and the Swedish south coast. The Traffic Separation Scheme with the cautionary area marked in the chart. The collision happened just south of the Svartgrund buoy. Screen shot from Marine Traffic.

Karin Høj was destined for Nyköping Falster in Denmark by way of the Kadettrinne. This meant that she was continuing her SW course as she had passed the Svartgrund buoy.

With her 12 knots, *Scot Carrier* was twice as fast as *Karin Høj*. At 0300 o'clock in the morning Scot Carrier started to overtake *Karin Høj* on her port (left) side. At Shortly after overtaking the Danish vessel, at 0323, *Scot Carrier* changed course to due West and swung towards *Karin Høj* hitting her midships and turning her completely over (see Figure 2). Both crew members onboard the Danish barge both died.

The accident investigation is still ongoing, and in May 2022 not published. The above details of the accident have been gathered trough public media (e.g. gCaptain, 2021a and 2021b;) and an AIS recording (Ship Radar, 2021).

The collision regulations, COLREGS Rule 13, states that "any vessel overtaking any other shall keep out of the way of the vessel being overtaken." Further that "any subsequent alteration of the bearing between the two vessels shall not make the overtaking vessel a crossing vessel within the meaning of these Rules or relieve her of the duty of keeping clear of the overtaken vessel until she is finally past and clear."

Fig. 2. *Scot Carrier* (red track) was overtaking *Karin Høj* (black track). *Scot Carrier* turned starboard (right) shortly after passing Svartgrund buoy and collided. Track derived from ShipRadar, (2021).

From Rule 13 it seems clear that *Scot Carrier* violated this rule. The AIS track is not conclusive on whether or not *Karin Høj* did any last-minute evasive maneuvers. The Swedish coast guard, boarding *Scott Carrier* after the accident raised criminal charges against the watch officer and one other crew member for driving under the influence of alcohol. It remains to be seen if *Scot Carrier's* starboard turn was automatically executed by the autopilot in track-following mode or manually executed by the watch officer on the bridge.

This accident raises some interesting questions regarding autonomous ships. Was this a case of misunderstood intentions? Did *Scott Carrier* assume that *Karin Høj* would also turn to a Westerly course? And *Karin Høj* that *Scot Carrier* would continue straight ahead? Or was it an automatic turn with no one awake on the bridge? When the accident investigation is ready we will know, but the case raises in either case interesting questions regarding autonomous shipping.

2. Assumptions of route intentions

An automatic navigation or collision avoidance system on an autonomous *Scot Carrier* or *Karin Høj* would have to make assumptions on what was the intentions of the other vessel. If the red vessel in Figure 3 is intending to follow route D (turning starboard) she must know the intentions of the black vessel. If she assumes the black vessel will also turn starboard and follow route B, she can herself turn without problem. However, if the black vessel intends to continue straight ahead along route A, the red vessel must consider either to slow down and let the black vessel pass ahead, or maybe make a 270 degree round turn to port and pass behind the black vessel.

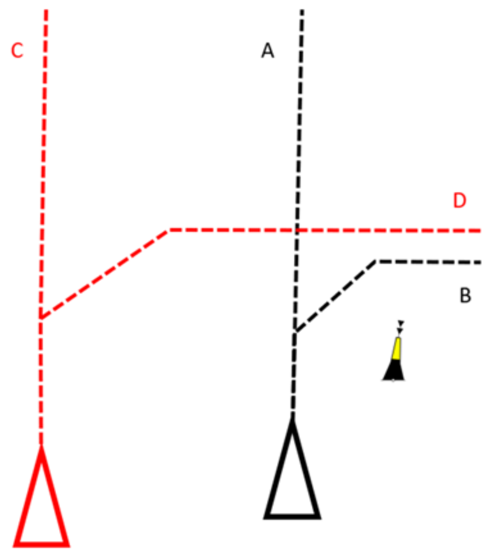

Fig. 3. The red ship can only follow route D if she assumes that the black ship follows route B. See text for details. Illustration by the author.

In the same way, an automatic navigation system on the black vessel must be aware of the intentions of the red vessel. The assumptions made by an AI algorithm about the other vessels intended route will be of crucial importance to successful and safe maneuvering if autonomous shipping is to be realized.

In the following I will discuss some present and potential future methods for making these assumptions and I will finally come with a suggestion of how this problem can be solved.

3. Potential solutions to automatically infer route intentions

3.1. Extrapolating course and speed

A very common way of making assumptions about the risk of collision is by assuming that the other vessel will continue with her present course and speed, and just extrapolate it. If there is a crossing situation, the risk of collision can be checked from a bridge by taking the bearing to the other vessel. If the bearing is not changing as the time goes on, there is a risk of collision, and the give-way ship must take action.

Course and speed as well as rate-of-turn is today transmitted by the Automatic Information System (AIS) for all SOLAS ships. These messages are sent out every 2-10 seconds. This message contains dynamic real time data like the ships position, course, speed and rate of turn. It also contains pre-programmed statical date like the ship type, name, cargo and port of destination.

Fig. 4. Encounter in the Oslo fjord. *Color Hybrid* and *Andenes* is heading into a close quarter situation. The red dotted heading line in front of each AIS target is an extrapolation of present movement for the next 10 minutes. See text for details. (Screen dump from kystinfo.no 20220509 at 14:38)

An autonomous navigation system can use this data to extrapolate present course, speed and turn-rate. In just the same manner it can be visualized with AIS symbols on the radar or ECDIS screens. In Figure 4 we see a screen shot from Kystinf.no with three vessels in the outer Oslofjord, two Color Line ferries on the route Sandfjord–Strömstad and the outbound coastguard vessel *Andenes*. The dotted line in front of the AIS symbols are the extrapolated course speed vector here set on 10 minutes showing the distance that the vessels will sail during that time, given that they keep the present course and speed. (Behind each vessel is also a full line showing passed track with time stamps.)

The COLREGS have also the requirement for “stand-on vessels” that they shall keep their course and speed. But in an archipelago scenario, ships can not keep a steady course and speed but must instead follow the fairway. Considerations also needs to be taken to wind, current and under keel clearance.

Extrapolating course and speed is useful and can be implemented in systems today. However, the method is best used in open sea where ships are not expected to change course and speed. It is not reliable in confined and densely trafficked waters where frequent course and speed changes might occur. Knowledge about the local traffic patterns will improve the methods validity.

A word of caution: AIS has some vulnerabilities such as being easy to jam and spoof or that ships can simply turn off their transponders. It has however, historically shown great reliability.

3.2. Local knowledge

A pilot onboard (or in the Remote Operation Centre ashore) may have knowledge about the behavior, destination and preferred routes of ships in an area. In the *Karin Høj* and *Scott Carrier* case above a local pilot would know about the danger of precisely the situation in question, he or she would know about the behavior of vessels normally passing through the area like the ferried between Bornholm, Denmark and Sweden, the roro companies taking trailers between the Baltic countries and Europe, etc.

However, for autonomous shipping, the question is still open as to whether, and in such a case how, a piloting service should be designed.

3.3. The AIS “destination” message

Another way of making assumptions about a vessels intended track is through another piece of information sent out by the ships AIS transponder: the port of destination. If you know the destination port, you can in many cases infer the route. In the example in Figure 4, the ferry *Tom Sawer* is under way from Klaipeda to “SE TRG” (Trelleborg, Sweden) and as the screen shot is taken when the ferry is outside the Swedish south coast there is pretty much only one way the ferry can take. A label displaying user customizable ships data, including the destination, can be set when hoovering over the target on a radar or ECDIS screen – as in Figure 4 from Marine Traffic.

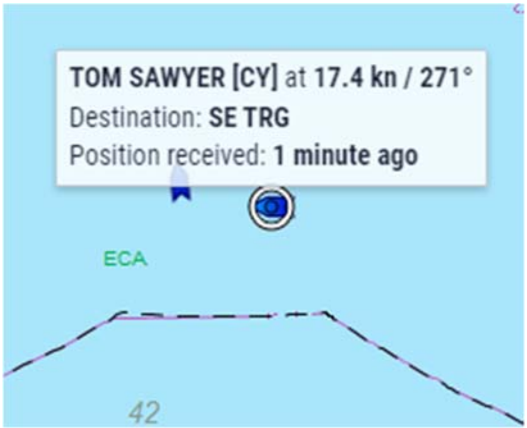

Fig. 4. An AIS label can be brough up on most radar and ECDIS screens containing user customable information from the AIS message. Here we can see the Cyprus registered ferry (blue symbol) *Tom Sawyer* with destination SE TRG meaning Trelleborg Sweden. (Screen dump from Marine Traffic 20220504 at 10:39.)

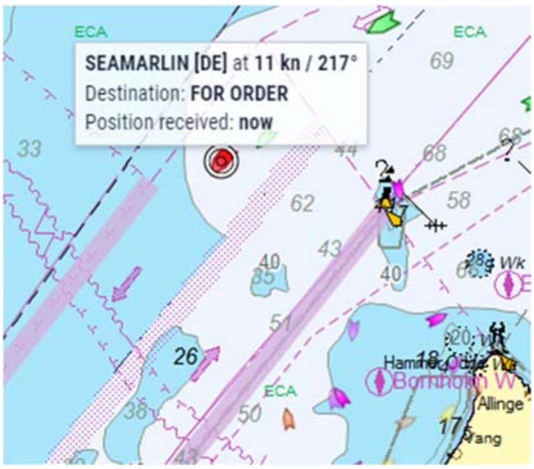

Fig. 5. On this AIS label we can see the Germain registered tank ship (red symbol) *Seamarlin* with destination “for orders”. In this case no assumption about intended track can be made. (Screen dump from MarineTraffic 20220504 at 10:41.)

However, some ten years ago this author was making an observation study onboard a tanker passing this area loaded with gasoil from Estonia to “Rotterdam for orders”. This is not an uncommon destination when the cargo is not yet sold on the spot market and traders are working on selling the cargo as the ship is underway. The captain planned to slow steam though the Great Belt, passing the norther tip of Denmark and then down towards the Southern North Sea and Rotterdam where many potential buyers are located. The intended route was consequently through the Great Belt. Passing Bornholm, the cargo was sold to Hamburg and the destination thus suddenly shifted as well as the intended track which changed from the Great Belt to the Kiel Canal, as now speed became a factor. As the destination changed, so did the intended track. In Figure 5 we can see such a ship passing the Strait of Bornholm. No assumptions of intended track can be made here.

3.4. Traffic density plots

In making assumption of ships intended tracks, so called traffic density maps can be of help. A density map is a statistical record of ship tracks during a specific period of time. In Figure 6 we can see all ship tracks for 2021 overlaid on the nautical chart of the area in the Strait of Bornholm. The color gradient is a heat map going from few ships in bluish colors over green, yellow and red for the most intensely trafficked tracks.

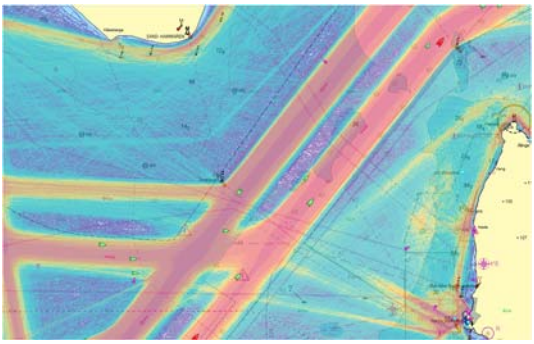

Fig. 6. Ship traffic density maps show the tracks of all ship tracks over a period of time (here for 2021). The tracks are color coded so that more tracks results in a warmer color. See text for details. (Screen dump from MarineTraffic 20220509 at 12:20.)

Historical AIS data (available e.g. by marinetraffic.com or kystinfo.no) allows us, or an autonomous system, to drill down even further into the statistical distribution of ship tracks. In Figure 7 we can see the 2021 tracks of cargo vessels in dark green compared to tracks of "tugs and special crafts (like *Karen Høj*) in light blue.

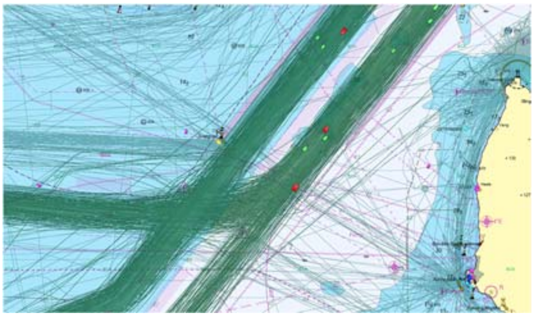

Fig. 7. When a traffic density map is filtered on ship type the individual tracks for a period of time become visible. See text for details. (Screen dump from MarineTraffic 20220509 at 13:28.)

When AIS data is filtered on historical track of an individual ship in regular line traffic we can make even stronger assumptions about the intentions of a ship. In Figure 8 we see the historical tracks of the catamaran ferry Express 1 which goes back and forward between Ystad in Sweden and Rønne on Bornholm.

Fig. 8. When we look at the historical track of an individual ship for a period of time, we can make even stronger assumptions about the ships intentions. Here the ferry *Express 1*. See text for details. (Screen dump from MarineTraffic 20220509 at 13:40.)

But in cases when we base assumptions on traffic density maps, we must be aware of that the historical behavior of ships or individual ships is not by necessity an absolute prediction for future behavior.

3.5. Reference routes

Another possible method for an autonomous navigation algorithm to infer the assumed route of another ship could be by checking the availability of traffic Separation Schemes or, in some countries, "reference routes" or similar. We are already acquainted with the Traffic Separation Scheme (TSS) in the Strait of Bornholm. A TSS is a mandatory regime by the IMO and according to COLREGS Rule 10 a vessel scheme shall:

"(i) proceed in the appropriate traffic lane in the general direction of traffic flow for that lane;

(ii) so far as practicable keep clear of a traffic separation line or separation zone;

(iii) normally join or leave a traffic lane at the termination of the lane, but when joining or leaving from either side shall do so at as small an angle to the general direction of traffic flow as practicable."

Further, a ship should as "far as practicable, avoid crossing traffic lanes but if obliged to do so shall cross on a heading as nearly as practicable at right angles to the general direction of traffic flow" (IMO, 1972).

From this we understand that the traffic flow in a TSS is very predictable, as we also can see from the density maps in Figures 6 and 7. But we also understand the ambiguity at junctions and at the endpoints of a TSS remains.

In some countries, like in Norway, the coastal administrations have started to publish what they call "Reference Routes" on national waters. See Figure 9 for a Norwegian example.

The Norwegian Coastal Administration (NCA) publishes reference routes and route information to assist route planning. The service includes all major ports of Norway, as of January 2022. The routes are developed for vessels up to 150 m length and 9 m draught, with some exceptions (NCA, 2022).

The reference Routes can be downloaded in a standard format that can be merged into a voyage plan in the ECDIS.

An interesting feature is that most Reference Routes have two separated one-way lanes, although not being officially an IMO TSS. Only in very narrow sounds are the two lanes merged into one dual-traffic lane.

If ship use these Reference Routes it will increase the predictability of ships intentions, particularly in combination with the AIS destination message. The situation could be compared with car navigation using route suggestions in Google maps. With the exception that all ships have ability to drive "off-road" to a much higher degree than cars.

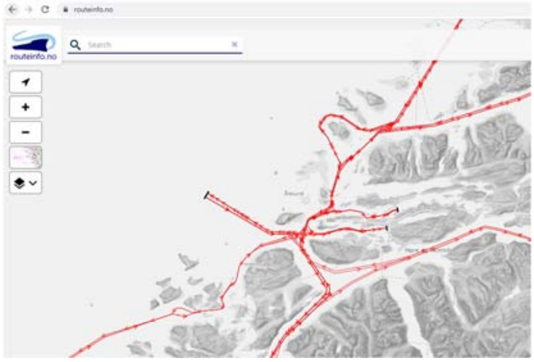

Fig. 9. On the Norwegian Coastal Administration's web site routeinfo.no so called "reference routes" can be downloaded and merged with the voyage plan in an ECDIS. (Screen shot from Routinf.no 20220509.)

In confined waters a computation of available water depth and a vessels draft (part of the AIS message) could also add to the probability of an assumption. However, the assumption would still remain a "guess" albeit an educated one.

A final interesting possibility for the future is using the e-Navigation concept of "route exchange".

4. Route Exchange

In 2006 IMO approved a proposal by Japan, Marshall Islands, Netherlands, Norway, Singapore, United Kingdom and United States to develop an "e-Navigation strategy". The objective of the proposal was to "develop a broad strategic vision for incorporating the use of new technologies in a structured way and ensuring that their use is compliant with various navigational communication technologies and services that are already available, with the aim of developing an overarching accurate, secure and cost-effective system with the potential to provide global coverage for ships of all sizes" (IMO, 2006).

The point with the e-navigation concept was to share digital data to the benefit of safety, efficiency and protection of the environment. As an example: all ships have to make a voyage plan "from birth to birth" before departing. If these voyage plans where shared openly e.g., "single points of failure" could be avoided, such as a ship straying off its course, whether deliberate or because an officer-of-the-watch (OOW) was making an error or falling asleep. In Figure 10 we see an example of how *Scot Carrier* could have used route exchange to query the intentions of

Karin Høj. (The accident report is not published yet so we do not know if there was any voice communication on VHF involved in the accident.)

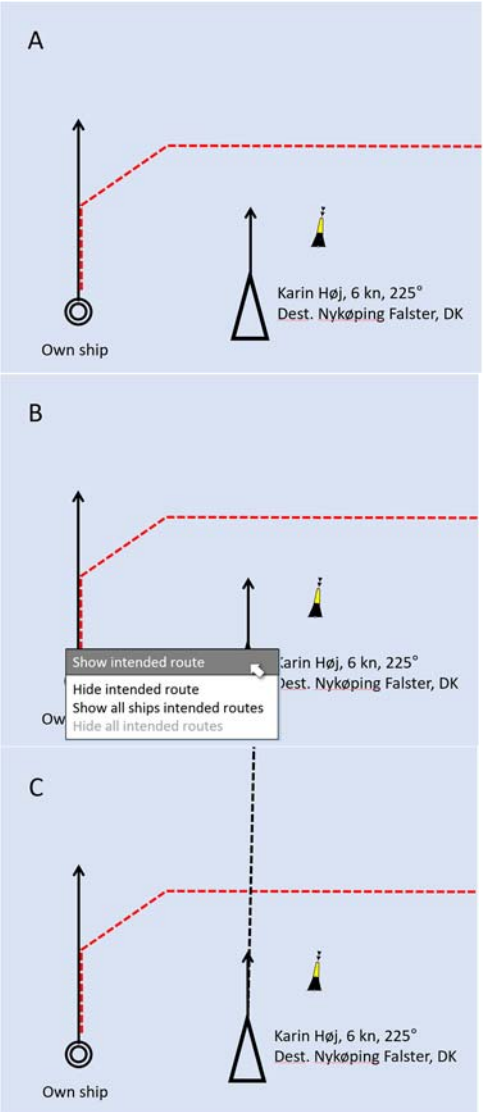

Fig. 10. An example of how “route exchange” could be used in the *Scott Carrier-Karin Høj* case: when overtaking *Karin Høj* (A) the watch officer on *Scott Carrier* could right click on *Karin Højs* AIS symbol to “Show intended routes” (B), and the intended track of the target vessel is visualized (C). Illustration by the author.

In many research projects since, possible e-Navigation features have been investigated. The feasibility to share routes has been called “route exchange” and could potentially allow alarms to be triggered, first onboard and later ashore if a ship deviated from its planned route. Route exchange in different forms has been researched by e.g. Porathe et al. (2014, 2015).

Route exchange involves ships to share a complete voyage plan ahead of departure in a Ship Management System (STM, 2022). It would also allow vessels to transmit a number of waypoints ahead of its present position to ships within radio range. These ships will then be able to see directly on their radar or chart screens which way the other ships plan to go, as demonstrated in Figure 10.

The system could also be extended by displaying a box (a “moving haven”) to visualize not only intended track but also the area the ship has planned to be within. The “moving havens” would follow the planned speed and correlate with the destination ETA. The autopilot could be set to keep the ship within its “moving haven” and a time-slider allow the OOW, the VTS operator or an anti-collision system to check for collision risk ahead, see Figure 11. The ability to keep withing you own planned box would need to be recalculated over time due to weather and traffic (Porathe, 2020).

By dragging a time-slider future positions could be visualized. The precision for very long-term planning could be questionable but mid or short-term forecasts should be relatively precise. The system would then alert if the separation between boxes is compromised.

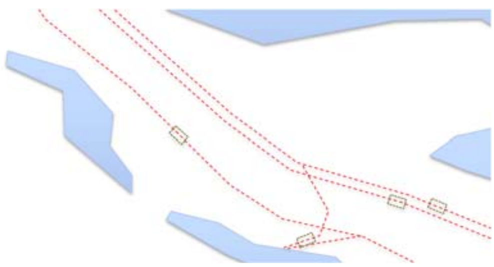

Fig. 11. “Moving havens”. An example of how “route exchange” could involve the time domain. The moving box shows the planned position of each vessel according to their voyage plan (or a VTS traffic organization scheme). The ship would then have to keep within its designated “haven”. Illustration by the author (Porathe, 2020).

Using these “route exchange” features to the full would allow an autonomous navigation system good “situation awareness” of other ships intentions and thereby better collision avoidance capacity.

A word of caution may be in place here. Mechanisms for avoiding that ships send out erroneous intentions must be found, e.g. intentions are turned off if a ship deviates from its track or "moving haven".

In a centre for remote operators of autonomous ships "automation transparency" will be essential. This involves showing other ship's assumed intentions (with alternatives) and what they are based on so that operators can evaluate and override the autonomous navigation system if needed.

5. Conclusion

Assumptions about other ships intended routes have vital safety implication for automatic collision avoidance systems for autonomous ships. The aim of this paper has been to discuss different potential methods for making these assumptions.

All these methods will be essential to include in an autonomous navigation system, but foremost I want to point to the e-navigation feature of "route exchange" as an important component.

I have intentionally refrained from discussing voice communication over VHF radio in this paper. Remote operators will have the possibility to use voice communication but monitoring several ships at a time is a potential problem. Automated synthetic voice transmissions between humans and machines are being studied in the SFI AutoShip project and research findings will be published shortly.

Acknowledgement

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